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Properties of Soils and Soil Deposits

NEW METHOD FOR DETERMINATION OF TENSILE STRENGTH OF SOILS

by
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ABSTRACT

This paper describes a new and simple test technique for determining the tensile strength of soils. A cylindrical soil specimen is used applying two steel punches at the center on both top and bottom surfaces of the specimen. Based on the perfect plasticity theory, a simple formula for computing the tensile strength of soils is developed.

The fundamental relationship between tensile strength and environmental variables is examined. The comparisons of tensile strength determined from double punch tests and split tensile tests for various materials including concrete, mortar, and bituminous concrete are presented.

It is concluded that the double punch test could be used easily for determining the tensile characteristic of soils and to predict the bearing capacity behavior of soil mass which will provide a better design criterion for embankments and retaining structures.

INTRODUCTION

Tensile strength of soil is one of the important strength parameters in the field of soil mechanics. However, engineers often consider that the tensile strength of soil is assumed to be zero because it is a relatively small value comparison with compression strength and the lack of a satisfactory measuring technique.

The importance of cracking failure related to the tensile strength of materials in many highway pavement and earthfill dams has been given considerable attention in recent years. Leonards and Narain[14] developed a laboratory measuring technique to measure the tensile-bending stress of soil by use of clay-beam and to predict the cracking behavior of earth dams. George[10] has applied the theory of brittle fracture to evaluate the cracking growth and the effects on stabilized soil-cement.

For measuring the tensile strength of material, the split tensile test has been widely used for concrete[1,5,20] and has been extended to measure the tensile strength of bituminous concrete[4,15], lime stabilized soil[16] and soil-cement[12,13]. Tschebotarioff et al[18] and Winterkorn[19] have used a modified Briquet Gang Model type to measure the tensile strength of various clay minerals. Recently, Chen[7,8] has proposed a double punch test which has been suggested as an alternative test method for determination of tensile strength of concrete.

The purpose of this paper is to develop both theoretically and experimentally the application of double punch test to cohesive soils which includes: (1) To develop an equation based on the perfect-plasticity theory that the tensile strength of soil can be computed; (2) To develop the fundamental relations between tensile strength and environmental variables; and (3) Comparisons of tensile strength results determined from double punch tests and split tensile test for various materials including concrete, mortar, and bituminous concrete.

DESCRIPTION OF DOUBLE PUNCH TEST

Using two steel discs centered on both top and bottom surfaces of a cylindrical soil specimen, the vertical load is applied slowly on the discs until the specimen reaches failure. The tensile strength of the specimen can be calculated from the maximum load by the theory of perfect plasticity. The schematic diagrams and the photos of the double punch test are shown in Figs. 1 and 2.

The effect of the sample size and the dimension of the disc have been studied by Hyland and Chen[11]. Based on the test of concrete and mortar, they have found that the effect of height-to-diameter ratio and disc size on the tensile strength is approximately a linear relation. Fang[9] has found that height-to-diameter ratio of the specimen varies from 0.8 to 1.2 and the ratio of diameter of specimen to the diameter of the disc varies from 0.2 to 0.3 are suitable for this test. For more convenience and practical manner, the Proctor mold (4" x 4") and CBR mold (6" x 6") with 1 inch and 1.33 inch (CBR piston) disc respectively are recommended[9]. For this study the Proctor mold was used for preparation of the soil specimen with 1 inch diameter disc. The disc should be rigid so that no bending occurs during the loading test.

THEORETICAL ANALYSIS

The theoretical basis of the formula for computing the tensile strength of a split tensile test has been derived from the theory of linear elasticity[17]. It has the simple form:

$$\sigma_t = \frac{2P}{\pi L d} \tag{1}$$

where

σ_t = simple tensile strength, psi

P = applied load, lbs.

L = length of specimen, inch

d = diameter of specimen, inch

It has been shown recently by limit analysis[7] that an identical formula of the problem can also be derived from the theory of perfect plasticity. A plasticity treatment of the double punch test for the concrete has been developed by Chen[8] and results for predicting the bearing capacity of concrete and rock are available[6,7,11]. It would appear that the same theory should be applicable to the soil double punch test because the bearing capacity behavior for soils can be closely related to the bearing capacity behavior of concrete blocks or mortar.

The theory cited in Ref. 6 is based on two assumptions. The first assumption is that sufficient local deformability of soils in tension and in compression does exist to permit the application of the generalized theorems of limit analysis to soils idealized as a perfectly plastic material. The second assumption is that a modified Mohr-Coulomb failure surface in compression and a small but non-zero tension cut-off is postulated as a yield surface for soils (Fig. 3). In Figure 3 q_u, σ_t, c, and ϕ denote the unconfined compression, simple tension strength, cohesion, and the internal friction angle of the soil, respectively.

Figure 4 shows diagrammatically an ideal failure mechanism for a double punch test on a cylinder specimen. It consists of many simple tension cracks along the radial direction and two cone-shape rupture surfaces directly beneath the punches. The cone-shapes move toward each other as a rigid body and displace the surrounding material horizontally sideways. The relative velocity vector δ_w at each point along the cone surface is inclined at an angle ϕ to the surface[6]. The compatible velocity relation is also shown in Fig. 4. It is a simple matter to calculate the areas of the surfaces of discontinuity. The rate of dissipation of energy is found by multiplying the area of each discontinuity surface by σ_t times the separation velocity $2\Delta_r$ across the surface for a simple "tensile" crack or q_u $(1 - \sin \phi)/2$ times the relative velocity δ_w across the cone-shape rupture surface for simple "shearing"[6]. Equating the external rate of work to the total rate of internal dissipation yields the value of the upper bound on the applied load P,

$$\frac{P}{\pi a^2} = \frac{1 - \sin \phi}{\sin \alpha \cos (\alpha + \phi)} \frac{q_u}{2} + \tan (\alpha + \phi) \left(\frac{bH}{a^2} - \cot \alpha\right) \sigma_t \qquad (2)$$

in which α is the as yet unknown angle of the cone, a is the radius of the punch and b and H are the specimen dimensions (Fig. 4).

The upper bound has a minimum value when α satisfies the condition $\partial P^u / \partial \alpha = 0$, which is

$$\cot \alpha = \tan \phi + \sec \phi \left\{1 + \frac{\frac{bH}{a^2} \cos \phi}{\frac{q_u}{\sigma_t} \left[\frac{1 - \sin \phi}{2}\right] - \sin \phi}\right\}^{\frac{1}{2}} \qquad (3)$$

valid for

$$\alpha \geq \tan^{-1} \left(\frac{2a}{H}\right)$$

and Eq. 2 can be reduced to

$$\frac{P}{\pi a^2} = \sigma_t \left[\frac{bH}{a^2} \tan (2\alpha + \phi) - 1\right] \qquad (4)$$

Using typical values of $q_u = 10\ \sigma_t$ and $\phi = 20°$, and assuming 2a = 1 in., 2b = 4 inches and H = 4 inches, the upper bound has a minimum value at the point where $\alpha = 14.2°$, and Eq. 4 gives

$$P \leq P^u = \pi\ (1.12\ bH - a^2)\ \sigma_t \tag{5}$$

It is found that the value of the coefficient 1.12 which appeared in Eq. 5 is not too sensitive to the internal friction angle ϕ. For example, ϕ varies from 0° to 30° and the value of the coefficient varies from 0.84 to 1.32, respectively. The average value of the coefficient is 1.08.

As concluded in Reference 6, the upper bound solution so obtained is in fact close to the correct values. It seems therefore reasonable to take Eq. 6

$$\sigma_t = \frac{P}{\pi\ (1.0\ bH - a^2)} \tag{6}$$

as a working formula for computing the tensile strength in a double punch test for all soils.

LABORATORY EXPERIMENTS

Specimen

Medium plasticity soil was selected for the study. Soil samples passed No. 4 sieves and air dried. A 4" x 4" Proctor mold was used for preparation of the remold specimen. Specimens were compacted in three layers with 5.5 lbs. hammer, 12-inch drop. 15, 25 and 55 blows per layer were applied. For the double punch test the procedures were followed as suggested by Fang[9]. One-inch diameter steel discs were used as shown in Fig. 1-a and 2-a. The rate of load application was 2-inches per minute. Simultaneously, duplicated specimens were made for the split-tensile test[2] and unconfined compression test[2,3].

Test Results

The load-deflection data and maximum load were recorded for all tests which include double punch, split-tensile and unconfined compression tests. The test results are summarized in graphical form as shown in Fig. 5 to Fig. 10. The double punch tensile strength was computed from Eq. 6 where b = 2 inches, H = 4 inches and a = 0.5 inches. The split tensile strength was calculated from Eq. 1 where L = 4 inches and d = 4 inches. For both equations P is the maximum load for the specimen. The cracking pattern for the double punch test is shown in Fig. 1-b and 2-b. The cone shape formation with two or three piece cracks are generally observed for the soils.

Figure 5 shows the density-moisture content relationships with three compactive efforts. Figure 6 shows the tensile strength versus molding moisture content with various compactive efforts and indicates that maximum tensile strength exists on the dry-side of the optimum moisture content. Figure 7 was interpreted from Figs. 5 and 6 and indicates that at higher moisture content, the density increase has a slight increase on tensile strength, however, at lower moisture content as density increases the tensile strength increases sharply.

Figures 8 and 9 show the comparisons of the tensile strength determined by double punch and split-tensile tests. Figure 8 shows only one type of soil with various molding moisture contents and compactive efforts. However, Figure 9 shows the tensile strength of soil comparisons with other materials such as concrete, mortar, and bituminous concrete. Good agreement between two tensile strength test results is indicated. Figure 10 shows the typical load-deflection curves for both double punch and split-tensile tests. For all the cases, the similar load-deflection patterns were found for both double punch and split tensile tests.

SUMMARY AND CONCLUSIONS

1. The double punch test is a simple test and easy to perform. No additional equipment is needed for the test which could be tied-in with routine CBR or compaction tests.

2. Based on the plasticity theory, a simple equation (Eq. 6) has been developed for computing the tensile strength of soils. This equation agrees well with the equation used for the split tensile test both theoretically and experimentally.

3. Equation 6 can be used for predicting the bearing capacity behavior of soil masses if the tensile strength is known. The ratio between tensile strength and unconfined compression strength is relatively constant. The tensile strength is equal to approximately 1/9 to 1/12 of unconfined compression strength.

4. Higher tensile strength existed on the dry-side of the optimum moisture condition.

5. When the cracking failure is significant, it is necessary to examine the tensile strength of the material. The double punch test can be used for both laboratory and field construction control.

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REFERENCES

1. Akazawa, Tsuneo, Tension Test Method for Concrete, Union of Testing and Research Laboratories for Materials and Structures, Bulletin No. 16, pp. 11-23, November 1953.

2. ASTM, 1970 Annual Book of ASTM Standards, Part II.

3. Bowles, J. E., Engineering Properties of Soils and Their Measurement, McGraw-Hill, 187 pp., 1970.

4. Breen, J. J. and Stephens, J. E., Split Cylinder Test Applied to Bituminous Mixtures at Low Temperatures, Jour. of Materials, Vol. 1, No. 1, ASTM, March 1966.

5. Carneiro, Fernando L. L. B. and Aguinaldo, Barcellos, Tensile Strength of Concrete, Union of Testing and Research Laboratories for Materials and Structures, Bulletin No. 13, pp. 97-127, March 1952.

6. Chen, W. F. and Drucker, D. C., Bearing Capacity of Concrete Blocks or Rock, Jour. of the Engineering Mechanics Div., Proc. ASCE, Vol. 95, No. EM4, pp. 955-978, August 1969.

7. Chen, W. F., Extensibility of Concrete and Theorems of Limit Analysis, Jour. of the Engineering Mechanics Div., Proc. ASCE, Vol. 96, No. EM3, pp. 341-352, June 1970.

8. Chen, W. F., Double Punch Test for Tensile Strength of Concrete, ACI, 1970, to appear.

9. Fang, H. Y., Method of Test for Tensile Strength of Soil, Rock and Stabilized Materials by Double Punch Test, Fritz Engineering Laboratory Report No. 348.4, Lehigh University, July 1970.

10. George, K. P., Theory of Brittle Fracture Applied to Soil Cement, Jour. of the Soil Mechanics and Foundations Div., Proc. ASCE, Vol. 96, No. SM3, pp. 991-1010, May 1970.

11. Hyland, M. W. and Chen, W. F., Bearing Capacity of Concrete Blocks, ACI, Vol. 67, pp. 228-236, March 1970.

12. Kennedy, T. W. and Hudson, W. R., Application of the Indirect Tensile Test to Stabilized Materials, Highway Research Record No. 235, pp. 36-48, 1968.

13. Kezdi, A., Erddrucktheorien, Springer Verlag, Berlin, 1962.

14. Leonards, G. A. and Narain, J., Flexibility of Clay and Cracking of Earth Dams, Jour. of the Soil Mechanics and Foundations Div., Proc. ASCE, Vol. 89, No. SM2, pp. 47-98, March 1963.

15. Livneh, M. and Shklarsky, E., The Splitting Test for Determination of Bituminous Concrete Strength, Proc. AAPT, Vol. 31, pp. 457-476, 1962.

16. Thompson, M. R., The Split-tensile Strength of Lime-stabilized Soils, Highway Research Record No. 92, pp. 11-23, 1965.

17. Timoshonko, S., Theory of Elasticity, Mc-Graw-Hill Book Co., New York, pp. 104-108, 1934.

18. Tschebotarioff, G. P., Ward, E. and DePhilippe, A. A., The Tensile Strength of Disturbed and Recompacted Soils, Proc. 3rd International Soil Mechanics and Foundation Engineering, Vol. 3, pp. 207-210, 1953.

19. Winterkorn, Hans F., The Science of Soil Stabilization, Highway Research Board Bulletin 108, pp. 1-24, 1955.

20. Wright, P. J. F., Comments on an Indirect Tensile Test on Concrete Cylinders, Magazine of Concrete Research, Vol. 7, No. 20, pp. 87-96, July 1955.

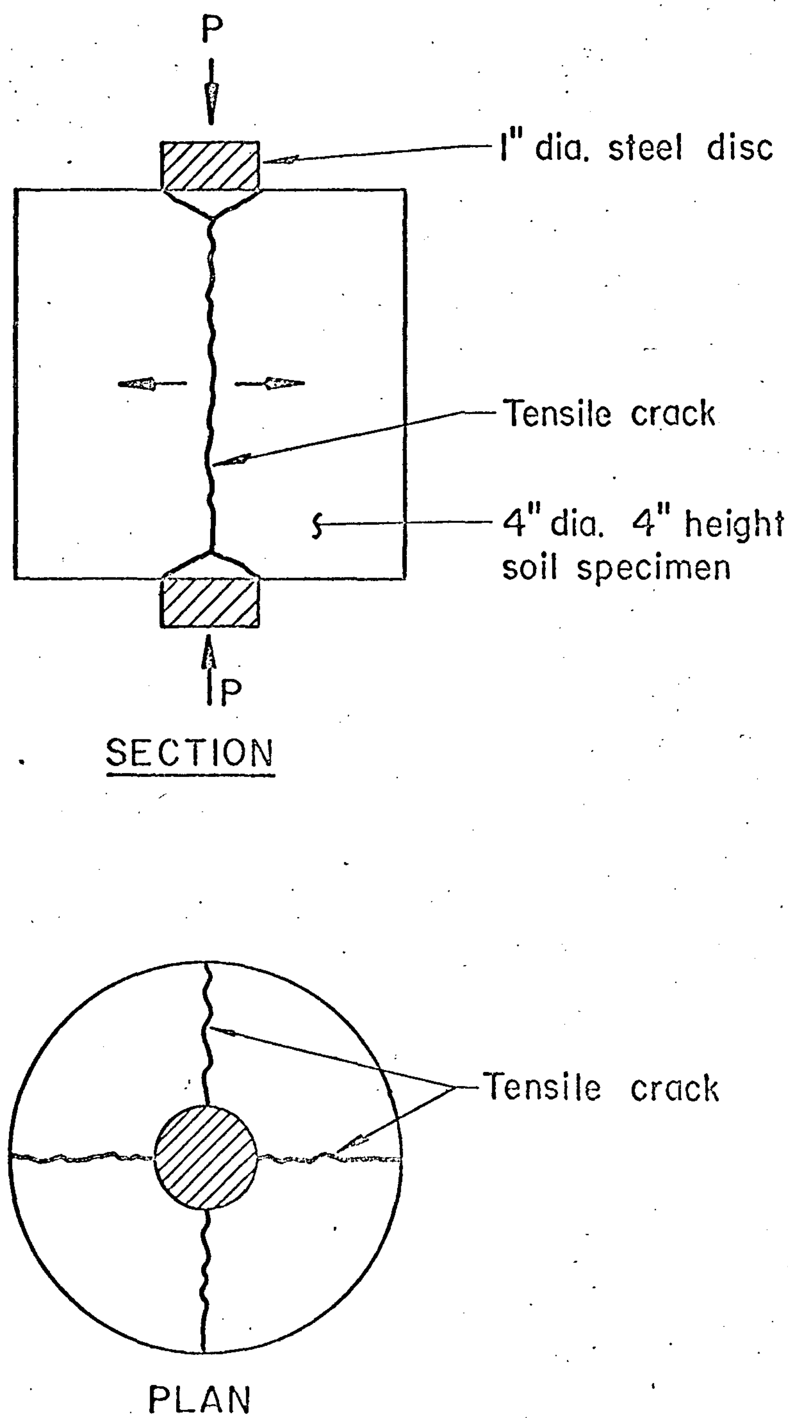
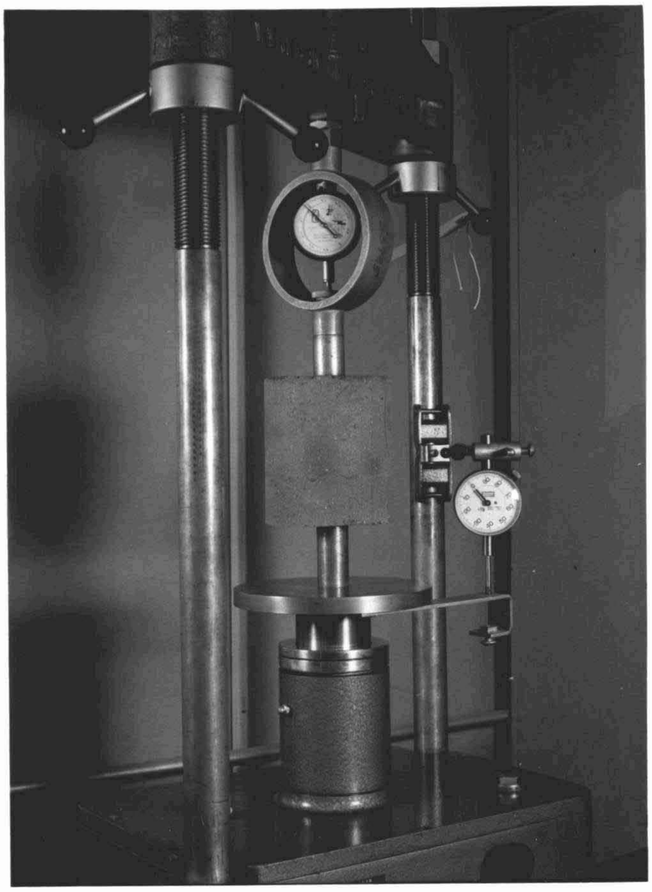
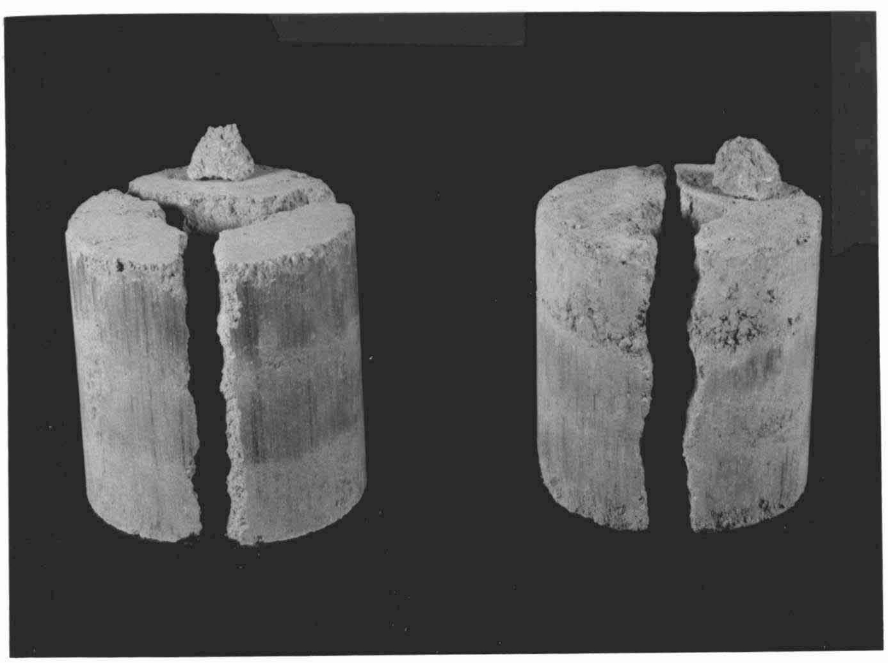


Fig. 1 Schematic Diagram of a Double Punch Test



a. Test Setup



b. Modes of Failure

Fig. 2 A Double Punch Test

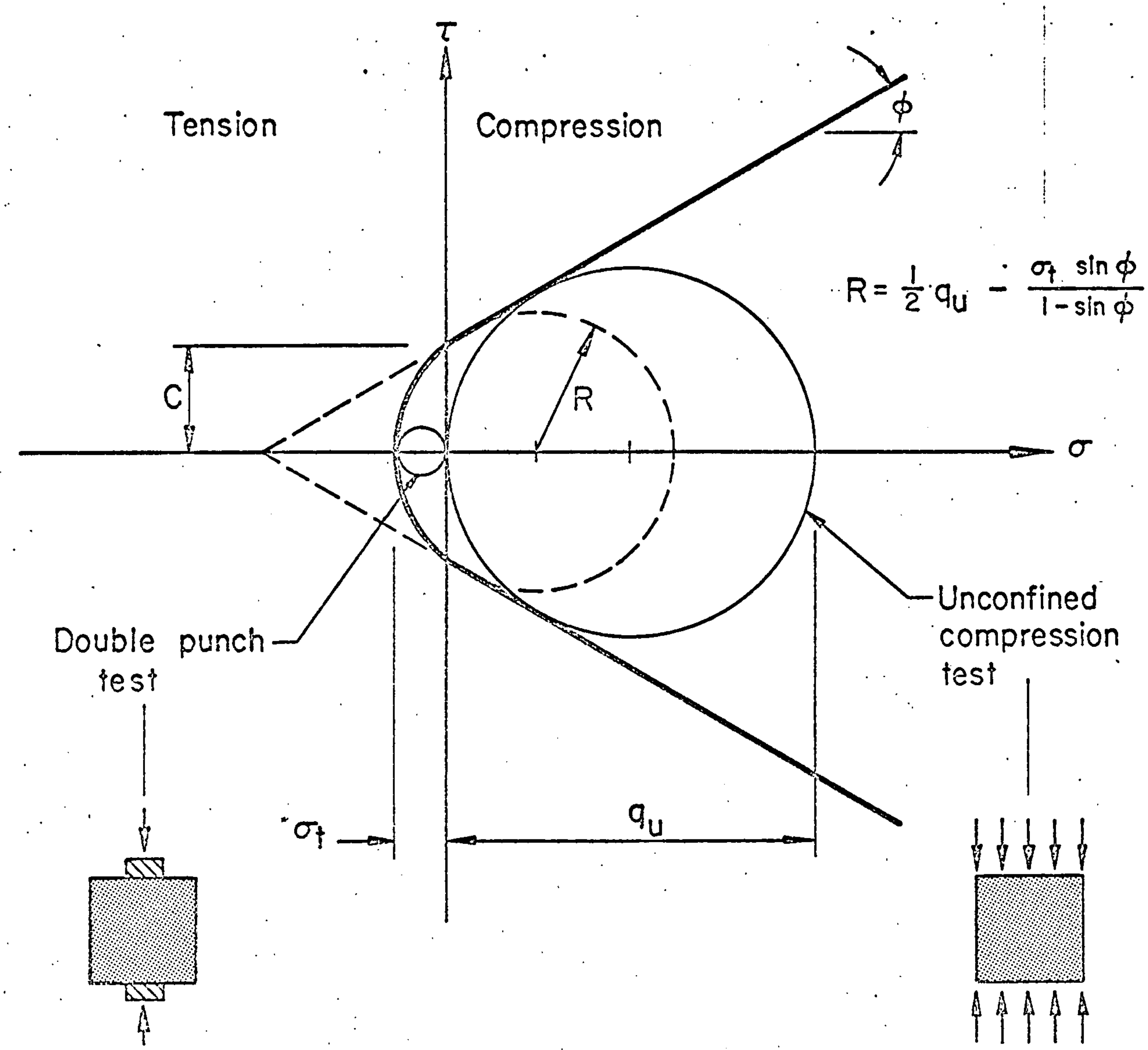


Fig. 3 Modified Mohr-Coulomb Criterion

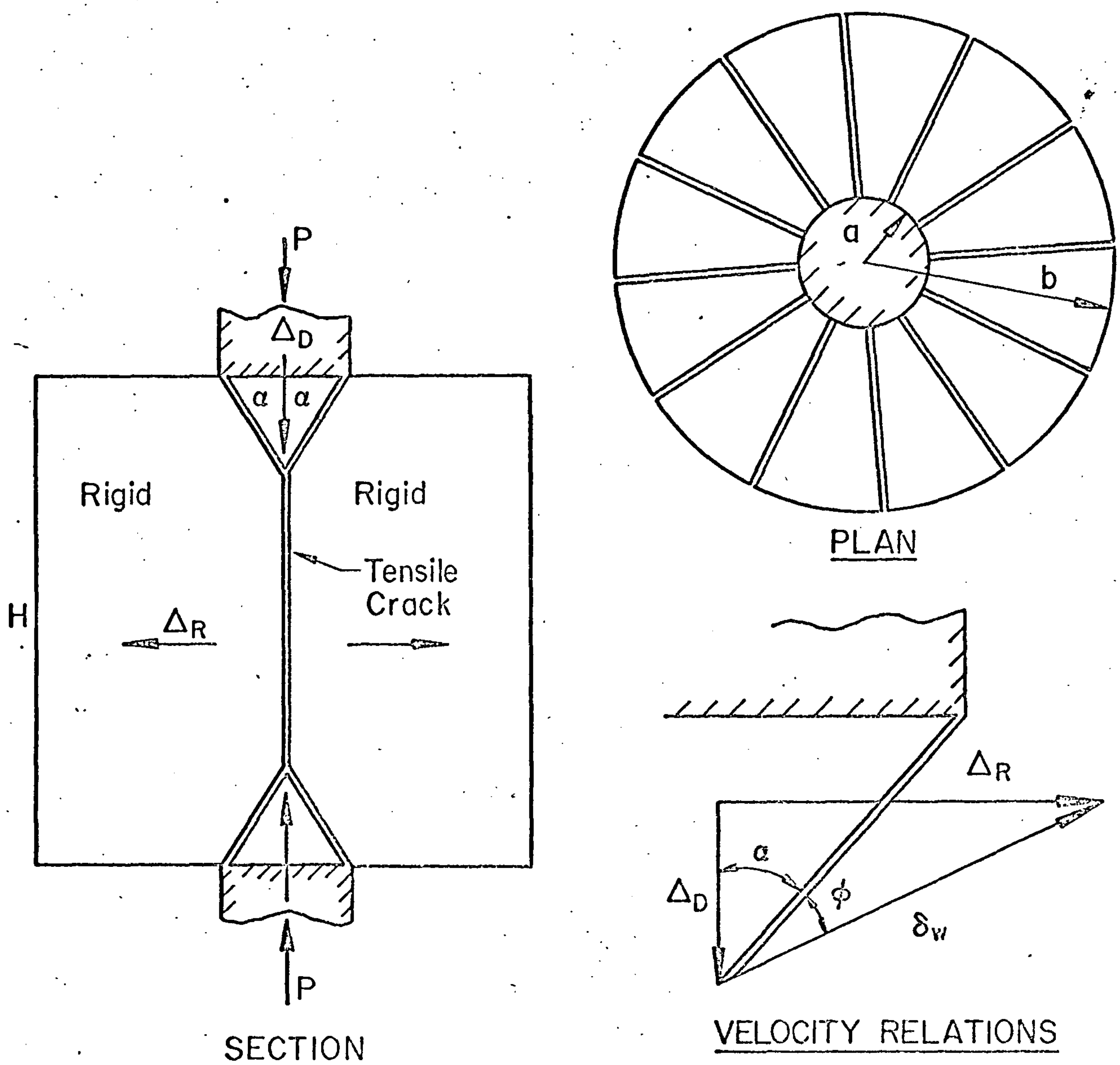


Fig. 4 Failure Mechanism of a Double Punch Test

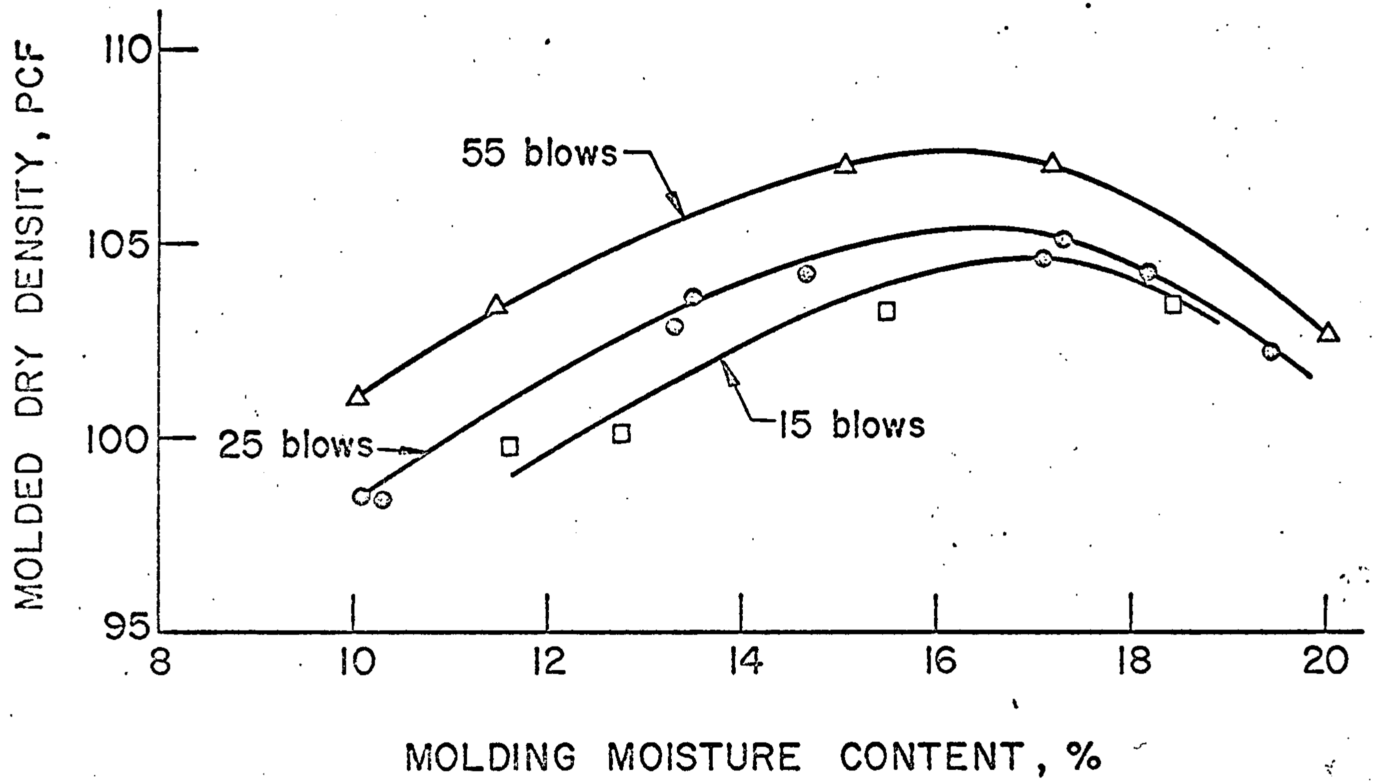


Fig. 5 Molded Dry Density vs. Molding Moisture Content

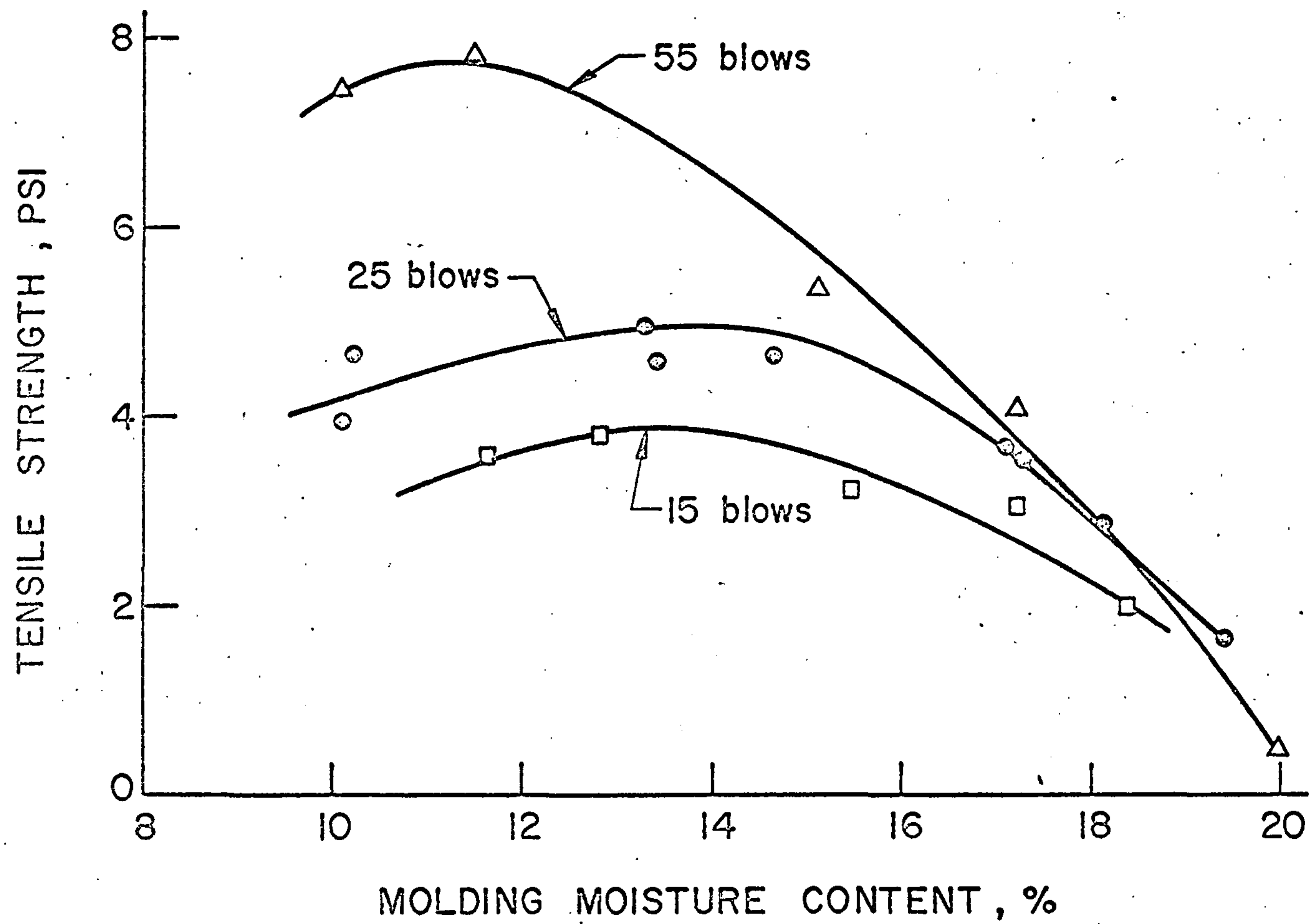


Fig. 6 Tensile Strength vs. Molding Moisture Content

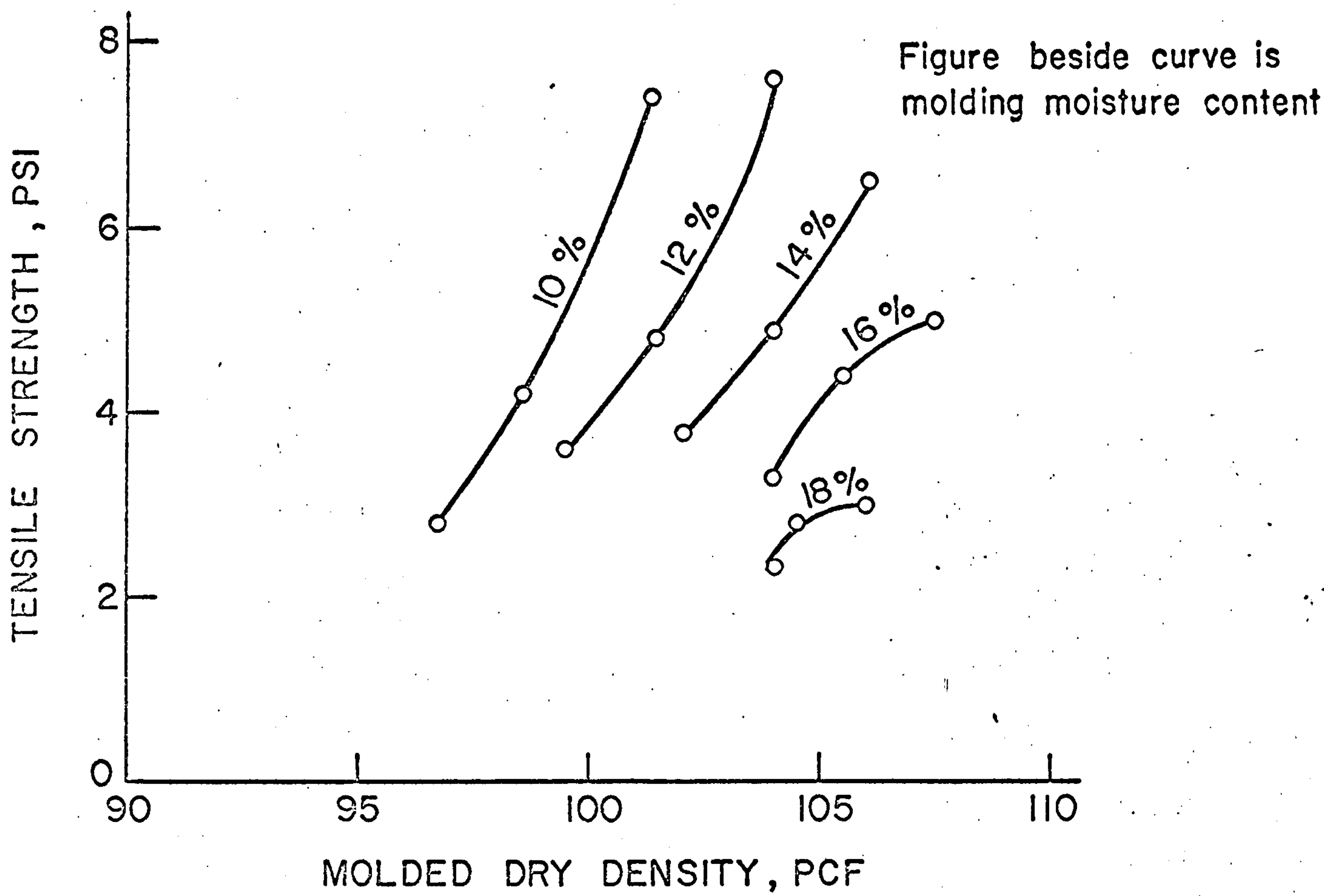


Fig. 7 Tensile Strength vs. Molded Dry Density

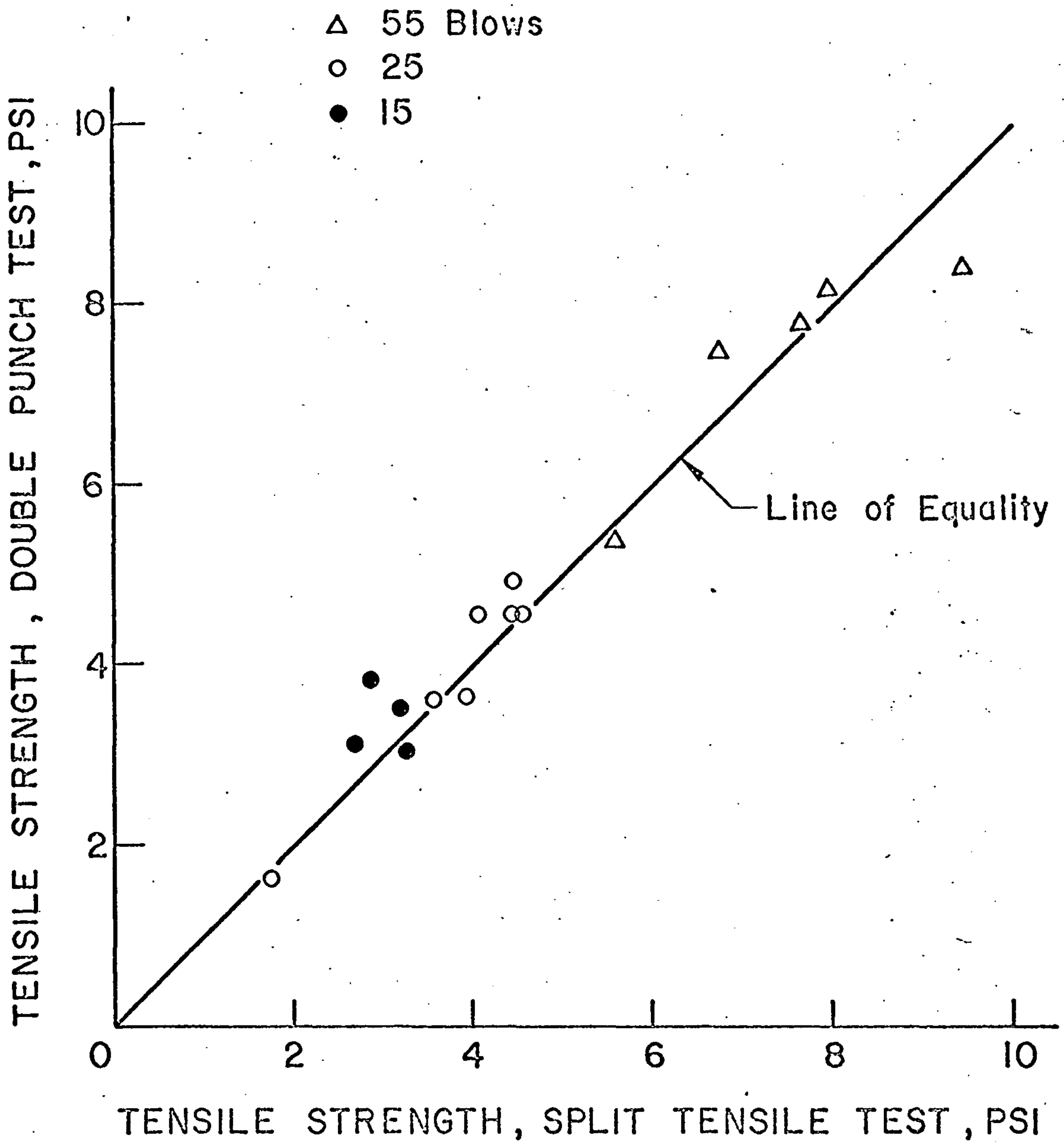


Fig. 8 Comparisons of Tensile Strength of Soil Determined by Double Punch and Split Tensile Tests

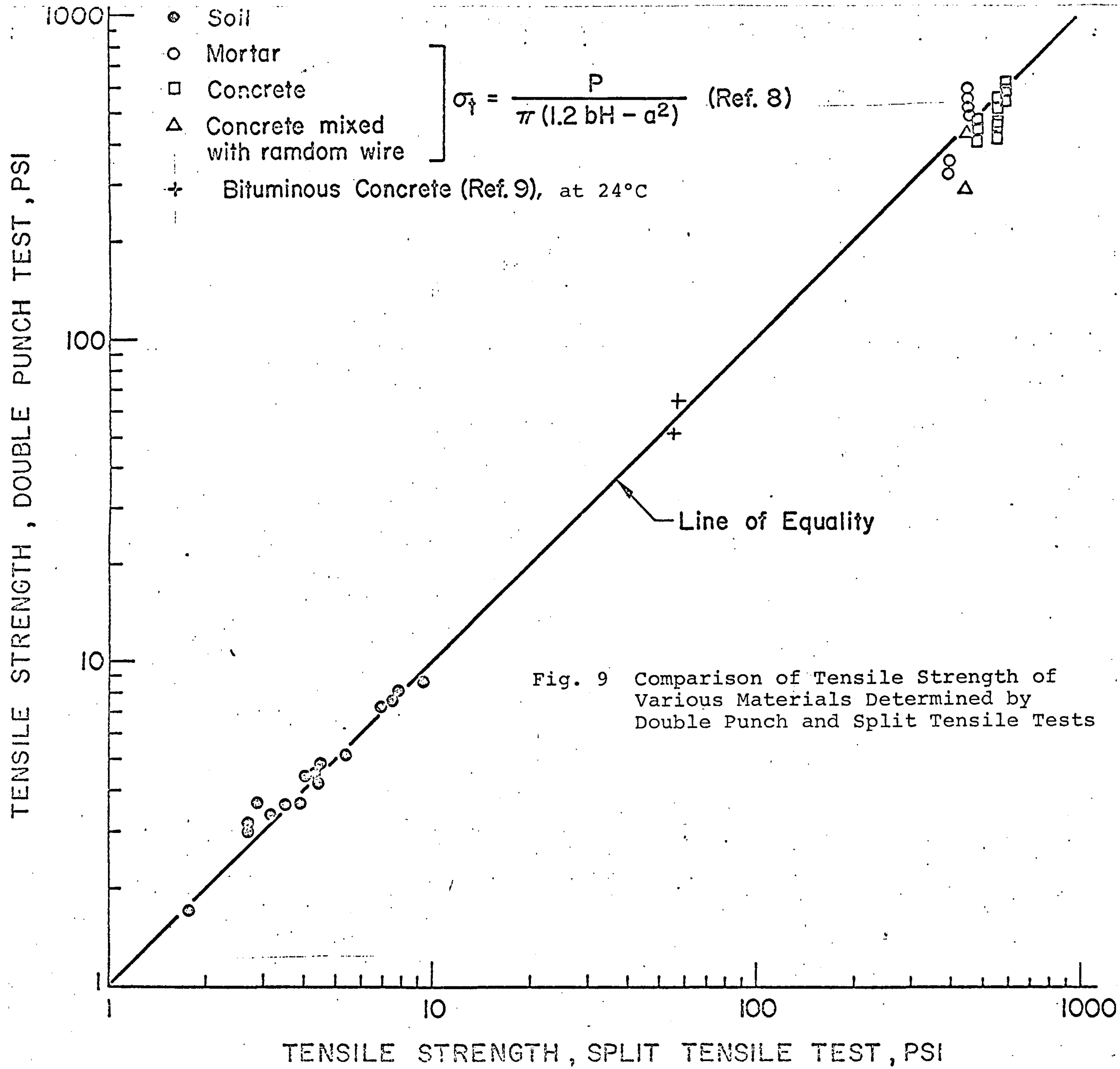


Fig. 9 Comparison of Tensile Strength of Various Materials Determined by Double Punch and Split Tensile Tests

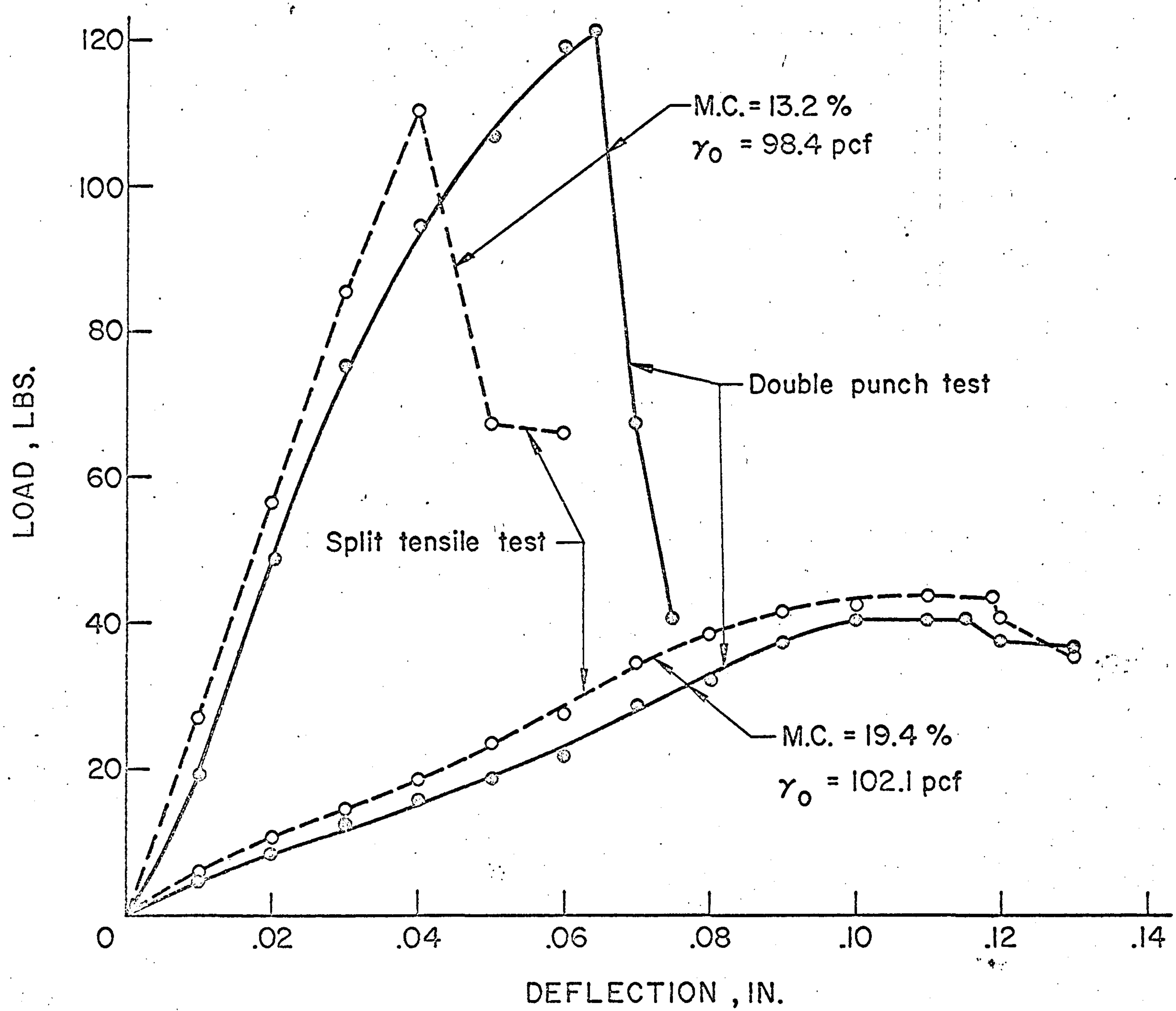


Fig. 10 Load-Deflection Curves